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Additional inventors are being named on the ______ separately numbered sheets attached hereto

TITLE OF THE INVENTION (500 characters max)

TABBED HEAT TRANSFER FINS AND AIR-COOLED HEAT EXCHANGERS WITH TABBED FINS

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Respectfully submitted,

SIGNATURE Paul J. White

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

TABBED HEAT TRANSFER FINS AND AIR-COOLED HEAT EXCHANGERS WITH TABBED FINS

BACKGROUND OF THE INVENTION

1. Field of the Invention.

[0001] The present invention relates generally to heat exchangers that utilize fins or plates on or in contact with tubes or pipes to transfer heat away from the working fluid in the tubes, and more particularly, to heat transfer fins, and heat exchangers or condensers that include such fins, that include a plurality of tabs extending from the fins to provide enhanced heat transfer on the air side of the heat exchanger with low and acceptable increases in pressure drop.

2. Relevant Background.

[0002] Heat exchangers are used extensively in industrial and consumer applications, and typically employ two moving fluids, one fluid being hotter than the other, to transfer heat to the colder fluid. Many heat exchangers currently in use, such as in air conditioners, automotive radiators, process industry air-cooled condensers, and boilers, transfer heat between a gas and a single or multi-phase liquid. Typically, such heat exchangers include a number of liquid conduits, e.g., circular, oval, or flat tubes or pipes, that are positioned within a shell or housing that defines a gas flow passage or chamber. The heat exchanger uses a fan or blower to force a gas, e.g., air, to flow within the gas flow chamber in a perpendicular (i.e., cross-flow) or parallel (i.e., counter-flow) direction relative to the liquid conduits. The resulting heat transfer between the liquid and the gas is directly proportional to the heat transfer surface area between the liquid and the gas, to the temperature difference between the liquid and the gas, and to the overall heat transfer coefficient of the heat exchanger. The overall heat transfer coefficient is defined in terms of the total thermal resistance to heat transfer between the gas and the liquid, and it is dependent on a number of characteristics of the heat exchanger design, such as the thermal conductivity of the material used to fabricate the

conduit and the local film coefficients along the conduit, i.e., measurements of how readily heat can be exchanged between the gas and the exterior surfaces of the conduit.

[0003] Although gas-liquid heat exchangers are widely used, the heat transfer effectiveness of these heat exchangers is low. The low heat transfer effectiveness leads to relatively high operating and capital costs for gas-liquid heat exchangers because a greater number of units and/or larger capacity units that require more power must be used to obtain a desired heat transfer. For example, geothermal power plants operate at low temperature differences between the gas and the liquid and, in these power plants, more than 25 percent of the cost of producing electricity is the expense of purchasing and operating gas-liquid heat exchangers or condensers. As a result of these high costs, continuing efforts are being made to improve heat transfer effectiveness of gas-liquid heat exchangers while at the same time controlling the manufacturing and operating cost to increase the likelihood that new heat exchanger designs will be adopted by industry and consumers.

[0004] Geothermal plants provide one example of a situation in which there is often not a sufficient supply of water or other cooling liquid for evaporative cooling, and heat must be rejected to atmospheric air. This heat rejection is accomplished through the use of large air-cooled condenser units in which air is forced through several rows of long individually finned tubes by large fans, i.e., a gas-liquid heat exchanger or condenser is employed. Each of the tubes carrying the hot working fluid has fins on their outer surfaces in order to provide a large heat transfer surface area. Finned-tube heat exchangers have been used for many years to improve the gas-side heat transfer rate by increasing the heat transfer surface area available for contacting the gas as it flows through the heat exchanger. In general, finned-tube heat exchangers are cross-flow heat exchangers that include a number of tubes, i.e., conduits, for carrying the liquid fabricated from aluminum, copper, steel, or other high thermal conductivity materials. The tubes pass through and contact a series of parallel, high thermal conductivity material sheets or plates, i.e., fins, which provide an extended heat transfer area for the tubes. The overall heat transfer area is based on the number and size of the included fins. The fins are separated a fixed distance, i.e., a fin separation distance, and define relatively parallel channels that direct the gas flow across and among the tubes. Heat

transfer occurs as the gas flows through the channel and contacts the surface of the fins and as the gas contacts the outer surfaces of the tubes. The highest heat transfer rate on a flat surface like a flat fin occurs at the leading edge of the surface and decreases with distance from the leading edge as a boundary layer develops and thickens causing the local heat transfer coefficient to decrease.

[0005] However, although finned-tube heat exchangers are widely used because they are relatively inexpensive to produce and do not create a large pressure drop, there are several operational drawbacks to finned-tube heat exchangers. For example, finned-tube heat exchangers have low heat transfer coefficients on large portions of the fins due to the development of thick boundary layers. Additionally, these heat exchangers have poor heat transfer in the wake or shadowed regions behind tubes as a majority of the gas flowing over a tube does not contact the backside of the tube or contact the portion of the fin surface that is shadowed by the tube.

[0006] In an attempt to increase the effectiveness of finned-tube heat exchangers, efforts have been made to vary the surface and overall geometry of the parallel fins to interrupt gas boundary layers or to make it more difficult for thick boundary layers to form on the fins. For example, finned-tube heat exchangers have utilized triangular or s-shaped wavy fins to enhance the heat transfer coefficient by disrupting boundary layer development and, also, by increasing the available heat transfer area. Alternatively, the surface geometry of flat, parallel fins can be enhanced, as is often done in refrigerant condensers, by slitting the fin three or four times in the areas of the fin between the tubes, thereby interfering with boundary layer development by creating offset surfaces on the fin that cause repeated growth and wake destruction of boundary layers. A number of heat exchangers have been developed that include structures on the fin surfaces that are designed to create turbulence in the channel between the fins to break up the boundary layer and increase heat transfer. Generally, these structures have been configured with a major portion of their surface area, such as winglets, vortex generators, and the like, facing the flowing gas or directed toward or into the gas flow path, e.g., to have a large profile relative to the gas flow path within the fin channel. However, the larger the profile or "form" placed in the flow path of the gas, including

the liquid tubes, the larger the pressure drop in the cooling gas as form drag is increased, which is generally an undesirable and often unacceptable result.

[0007] While some of the above changes in the fin surface and fin shape may provide somewhat higher heat transfer coefficients in finned-tube heat exchangers, the design changes also result in unacceptably large increases in pressure drop on the gas side of the heat exchanger that require increased expenditures on fan power. Additionally, many of these design changes have not been adopted due to unacceptably high manufacturing costs in producing the fins or due to increased maintenance costs as some of the fin surface structures snag or collect debris often found in unfiltered air typically used in air-cooled heat exchangers.

[0008] Hence, there remains a need for a more effective finned-tube, gas-liquid heat exchanger that provides improved heat transfer capabilities on the gas side of the exchanger while creating an acceptable increase in the pressure drop for the gas passing through the tubes and fins and while controlling manufacturing and maintenance costs.

SUMMARY OF THE INVENTION

[0009] The present invention addresses the above problems by providing an improved design for heat transfer fins that enhances the heat transfer rate on the gas or air side of heat exchangers with relatively low increase in pressure drop. Briefly, the fins include numerous tabs or secondary fins that are bent upward and downward from the body of the fin at a selected bend angle (such as between about 70 and 110 degrees and more typically, about 90 degrees). In this manner, the material of the fin body is retained for use in heat transfer with the air or gas flowing over the fins. Preferably, all or a majority of the tabs are aligned with the flow path(s) of the cooling gas to minimize the creation of turbulence and pressure drop (i.e., by minimizing creation of flow drag by only "showing" the tab's leading edge to the flowing gas). For example, the tabs may be substantially planar and aligned with their surfaces parallel to the main flow path (or in some cases, the local flow paths) of the cooling gas relative to the fin. In many cases, the tabs are positioned with their planar surfaces perpendicular to a leading edge of the fin to align the tabs substantially parallel with the main flow path of gas across the fin.

In this manner, heat transfer is significantly enhanced by reducing the thickness of the thermal boundary layer on each tab and by placing heat transfer surface area in contact with cooler portions of the flowing gas.

[0010] The tabs of the fin serve two main functions. First, the tabs are preferably arranged so as to serve as a plurality of sites for starting new boundary layers. This is achieved generally by offsetting the tabs (or adjacent rows of the tabs) such that downstream tabs are not shadowed by upstream tabs. Second, the tabs are preferably positioned relative to the flowing gas to enhance heat transfer. More particularly, the tabs typically have a tab height as measured from the surface of the fin body that allows the tab to extend out into the main boundary layers forming on the surface of the fin body, i.e., forming on both sides of the fin body. In one embodiment, the fin height is selected to between about 40 and 50 percent (e.g., about one half) of the size of the channel between adjacent fins, i.e., a fin separation distance and tabs are extended outward from both sides of the fin body. In this manner, the tabs place fin material into the coolest portion of the gas flowing on both sides of the tab. To achieve these functions, the tabs are formed by punching holes in the fin body but retaining a connection to the fin body on at least one edge. The material is then bent upward and/or downward relative to the fin body to extend at a bend angle from the two surfaces of the fin body, i.e., to allow the tabs to extend into the boundary layers that form on both sides of a fin.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Fig. 1 is a simplified heat exchanger according to the present invention illustrating one configuration in which tabbed fins or plates (such as those shown in later figures) can be employed to enhance heat transfer on the air or gas side;

[0012] Fig. 2 illustrates two fins according to the invention, one that is partially punched or has less tab density and one that is fully fabricated or has higher tab density, and a template that can be used for producing a tool to fabricate the fins shown;

[0013] Fig. 3 is a partial cross section of a set of fins (prior to placement on tubes) illustrating a side view of the fins, i.e., a view showing the planar surface of the tabs extending outward in this embodiment from both sides of the fins;

[0014] Fig. 4 is a partial sectional view of a heat exchanger similar to that shown in Fig. 3 illustrating more clearly the mating of the fins to a liquid tube and one exemplary configuration for the tabbed fins of the present invention (with fewer fins shown than would typically be included for ease of illustration);

[0015] Fig. 5 is another partial sectional view of a pair of fins according to the invention illustrating more clearly that selection of the height of the tabs for placement in the main boundary layers formed on the surfaces of the fin body;

[0016] Fig. 6 is a top view of a portion of a fin fabricated according to the present invention which is useful for illustrating that the tabs in adjacent rows are offset from each other to enhance heat transfer and for illustrating one useful pattern of the tabs on a fin relative to the fin collars/tube openings or to the tubes in a heat exchanger assembled according to the invention;

[0017] Fig. 7 is a cross sectional view of the fin shown in Fig. 6 taken at line 7-7 illustrating one arrangement for tabs on a fin (e.g., extending from both sides or surfaces of the fin body) and showing the bend angle and height of the tabs;

[0018] Fig. 8 is a perspective view of another fin fabricated according to the invention and further illustrating the concept of offset tabs utilized in most fin embodiments; and

[0019] Fig. 9 is a flow diagram for air or gas relative to a fin, such as the fin shown in Fig. 6 that can be utilized for designing the tab pattern on a fin, such as for selecting the alignment of the tabs relative to the leading edge of the fin body.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] The present invention is directed to heat exchanger fins employing tabs to increase heat transfer effectiveness, heat exchangers or condensers incorporating such tabbed fins or plates such as air-cooled, finned-tube heat exchangers, and methods of

making tabbed fins. Generally, each fin of the invention includes a multiplicity of small tabs or secondary fins that are formed by punching material (i.e., metal) out of the main fin body (i.e., creating a hole or opening) and the punched material is bent outward away from the main fin body in one or both directions from the surface of the fin. To minimize or control the creation of a vortex or increased pressure drop, the tabs are generally planar and aligned with the direction of the fluid, e.g., air, flowing over the fins in the channel between adjacent fins. In other words, a leading edge of the tab first contacts the flowing gas and the substantially planar body of the tab is aligned substantially parallel to the gas flow path or direction over the fin.

[0021] In some embodiments, it is assumed that there is one flow direction through the fins, such as perpendicular to the leading edge of the fins, and all of the fins are aligned parallel to this flow direction. In other embodiments, two or more flow directions within the fin channel are identified and fin tabs in different locations of the fin are aligned with these different flow paths to better limit creation of pressure drop. In some cases, a portion or subset of the tabs are aligned somewhat, such as less than 5 percent, off of the flow direction or flow path in order to redirect flow into areas of low flow such as the area behind or shadowed by a tube, whereby heat transfer is enhanced without creating a vortex at the tab. The tabs can take many shapes, such as square, rectangular, triangular, semi-circular, and a combination of these shapes, and are generally bent outward at about a right angle relative to the body of the fin but a smaller bend angle can be utilized to practice the invention. Tabs in adjacent rows are preferably offset from each other so as to avoid shadowing of subsequent tabs and to promote the creation of multiple boundary layers within the channels. The fins have a height defined by the amount of material removed from the fin body, and this fin height is less than the separation distance between fins, i.e., fin separation distance, and in many embodiments, the fin height is selected to be about one half of the fin separation distance (or less) to place the tabs within the coolest air flowing between the fins, i.e., at about the top of the boundary layer formed by the fin body. As will become clear from the following description, the use of tabbed fins according to the invention can significantly enhance heat transfer in finned-tube heat exchangers, with some tests indicating an increase of up to

approximately 68 percent with a corresponding increase in pressure drop of approximately 33 percent relative to smooth or plain fins.

[0022] In the following description, the use of tabbed fins according to the invention is explained most fully with finned-tube arrangements in which the fins or plates are arranged in a parallel fashion. However, it should be understood that the invention covers the use of tabs on many other arrangements of fins than just the ones shown. For example, it is anticipated that tabbed fins would be useful with helically wound fins. Additional applications of tabs to fins, whether or not the fins are applied to tubes, will be understood by those skilled in the art and are considered within the breadth of the invention and following description.

[0023] Figure 1 illustrates a simplified heat exchanger 100 that may be configured with tabbed fins according to the present invention. The heat exchanger 100 is a finned-tube heat exchanger or condenser and is shown in simplified form for ease of description. Generally, the heat exchanger 100 would further include a housing enclosing fins and tubes and, at least in part, define air flow channels, i.e., cause the air or other gas to flow between the fins and to define a gas inlet and a gas outlet. The heat exchanger 100 further would include one or more fans to draw (or push) air across the tubes and between the fins. These components are well known and hence, it is not believed necessary to illustrate or describe these components further to allow one skilled in the arts to understand and practice the invention. The heat exchanger 100 transfers heat energy from one fluid, i.e., the fluid in, F_{IN}, to another fluid or gas, i.e., the air in, A_{IN}, which results in a cooler fluid being output, i.e., the fluid out, F_{OUT}, and a hotter fluid or gas being output, i.e., the air out, A_{OUT}, from the heat exchanger 100. Of course, the fluids being cooled may be a gas or liquid or any mixture thereof.

[0024] Referring again to Figure 1, the heat exchanger 100 includes a plurality of plates or fins 110 that are arranged in a parallel manner and separated a fin separation distance. The fins 110 are tabbed, as described more fully in the following paragraphs and subsequent figures, to enhance heat transfer on the gas or air side of the exchanger 100. The fins 110 are typically pressed or fit together and spaced apart a fin separation distance by a set of tube collars 115 provided on one (or both) sides of each tube opening

in the fin 110. The tube collars 115 are sized to receive the liquid tubes 120, 130, such as copper or other metal tubes or pipes, which may have a circular cross section or another cross sectional shape such as oval (with the size, shape, location, material, and other properties of the tube not being limiting to the invention). The collars 115 provide the heat transfer surface between the tubes 120, 130 and the fins 110 and are often press fit onto the tubes, such as by inserting the tubes 120, 130 and then over pressurizing the tubes 120, 130 to cause the tubes 120, 130 to expand and contact the collars 115. Of course, fins may be attached to tubes in other ways including welding, brazing and the like and winding or wrapping (as is the case in foil fins that are helically wound onto tubes).

[0025] The incoming air, A_{IN}, is passed through the channel between the fins 110 and strikes the leading edges of the plurality of secondary fins or tabs (which are shown in a rows that are diagonally offset but other patterns can be used), thereby significantly increasing the amount of heat transferred from the incoming liquid, F_{IN}, via the tubes 120, 130, to the outgoing air, A_{OUT}. Additionally, the tabs on the fins 110 are shown to be all substantially perpendicular to the leading edges 140, the tabs, or at least a portion of the tabs, can also be arranged or aligned at different angles that are chosen such that in operation of the heat exchanger 100 the tabs direct flow smoothly around the tubes 120, 130 (and collars 115). In this manner, the tabs on the fins 110 can be utilized to shrink the wakes behind the tubes 120, 130. It should be further noted that although tubes 120, 130 are shown in Figure 1, the tabbed fin concept of the present invention could also be used in other heat exchanger, including those that do not use tubes. For example, but not as a limitation, tabs similar to the ones described herein may be used on serpentine-like fins in plate heat exchangers.

[0026] Referring now to Figure 2, portions of fins manufactured according to the present invention (or test fin sections) are shown along with a template useful in creating a punch tool for forming the holes and tabs in the fin bodies. The fin sections shown were formed for ½-inch tubing but of course, the size of the tube may vary to practice the invention (e.g., it is anticipated that the tabbed fins will be useful with 1-inch tubing often used in heat exchangers). The fin 210 is a metal (such as aluminum, copper, or other metal useful on the air or gas side of a heat exchanger) fully manufactured or

punched with numerous tabs extending outward from both sides or surfaces of the fin body, such as with about 50 percent extending upward and about 50 percent extending downward. Although it may not be clear from Figure 3, the tabs remain attached to the body of the fin, i.e., to retain the heat transfer material and surface area of the original fin body, and are bent outward so when the fin is used in a heat exchanger the tabs extend into the air stream flowing over the fin (as is explained in detail below. The tabs thus act as secondary fins or secondary fin surfaces.

[0027] As shown, a relatively large portion of the fin body surface area has been removed to form the tabs. For example, the surface area of the fin body removed or used to form the tabs may be selected from the range of 0 to 50 percent, and more preferably between 10 and 40 percent, and in one preferred embodiment, the surface areas used is about 20 percent of the fin body surface area. While initially it may appear that the area used to form the tabs should be maximized, there are limitations to how much material can or should be removed from the fin body. More particularly, the removal of fin body material reduces the volume of or mass of the fin body that is available to transfer the heat from the tube collar and tube contacting the collar to the tabs. Hence, testing may likely be required to identify for a particular fin and tube arrangement the amount of fin body surface area that should be used in forming the tabs.

[0028] The tabs shown are generally square (as can be seen clearly from the material removed to form the tab openings or holes) but numerous other shapes can be utilized, such as rectangular, triangular, and semi-circular. As will be explained below, the size of each tab is typically dictated by its height, i.e., what distance the tab is to extend away from the fin body. For example, if a tab is square and the height is selected to be one half of the distance between adjacent fins, then the sides of the square tab would each have a length equal to the tab height or one half the fin separation distance. The tabs are shown to be arranged in relatively linear rows in fin 210 and are shown to be more dense in areas of the fin in which flow is expected to be higher or highest, e.g., between tubes, in front of tubes, and away from housing wall surfaces. The fin 220 illustrates the use of a much smaller percentage of the fin body surface area to form tabs, and is also useful for showing an embodiment of the invention in which the fins are not necessarily arranged in neatly linear rows but "downstream" (e.g., tabs more distal from a leading

edge of the fin body) tabs are offset. In other words, downstream tabs are generally not positioned immediately behind an upstream tab or in the same air flow path to minimize shadowing and to encourage development of new boundary layers by each tab. Item 230 is a template useful for designing a punch tool for creating the tabs in a plain fin with darkened or colored holes indicating tabs to be punched to extend from a first surface of the fin body and the other holes indicating tabs punched the other direction. Again, the template 230 is useful for showing the downstream tabs are offset from upstream tabs.

[0029] Figure 3 illustrates a sectional view of a series of fins formed according to the present invention. As shown, air, A_{IN}, enters the channel formed between adjacent fin bodies and the heated air, A_{OUT}, exits the other end of the fin channel or air flow chamber of the heat exchanger. The view of Figure 3 can be thought of as a side view and shows that in this embodiment the fins include a plurality of tabs that extend outward from the fin body on both sides. As shown, the tabs are relatively planar with a square cross section. The planar portion of the tabs (i.e., the larger surface area portion of the tabs) are bent away from the fin body to be substantially parallel to the direction of the air, A_{IN}, through the channel between adjacent fin bodies. The fins or fin bodies are separated by a distance (typically determined by the height of the tube collars) that is shown as $D_{FIN\ SEPARATION}$ or $D_{F.S.}$. As shown, the tabs have a height (as measured from the fin body surface to the distal edge of the tab) that is less than about half of the $D_{FIN\ SEPARATION}$. In this manner, the tabs in one fin do not typically contact tabs in adjacent fins (which may cause assembly problems) but can be positioned within the cooler portion of the air, A_{IN}, such as at the top of the boundary layer (distal to the fin body surface). In other embodiments (not shown), the tabs extend from only one side of the fin body, and in some embodiments, the fin tabs extend outward more than one half of the fin separation, $D_{FIN\ SEPARATION}$.

[0030] Figure 4 illustrates in more detail a sectional view of a heat exchanger of the present invention. As shown, a pair of fin bodies 420 are placed in contact with each other via tube collars 422 and the collars are press-fit onto a tube 430 that is used for carrying a hot fluid, F_{IN} through the heat exchanger. The pair of fins are separated by a distance, $D_{F.S.}$, and the tabs 404, 410 shown on the fin bodies 420 extend outward from both surfaces 424, 428 of the fin bodies 420 a tab height, H_{TAB}. As discussed previously,

the tab height (or distance at which they extend when not configured with a bend angle of approximately 90 degrees relative to the body surface 424, 428) is typically selected to be less than the distance separating the fins, $D_{F.S.}$, and more typically, as shown, is selected to be about 40 to 50 percent of this distance, $D_{F.S.}$. The tab 404 is shown to include a leading edge 406 and a trailing edge 408. The tab 404 is bent or formed in a manner that positions the leading edge 406 to contact the incoming air, A_{IN}, and such that the planar area of the tab 404 is substantially parallel to the flow path of the air, A_{IN}. Tab 410 is shown to be generally square in shape but to include rounded shoulders 414 such that its leading edge is less likely to snag or catch debris in the incoming air, A_{IN}, that might clog the air flow channel between the fins and reduce heat transfer and/or increase pressure drop. Some of the tabs shown are more semicircular in shape indicating that the shape of the tabs 404, 410 can vary on differing fins or within a single fin to practice the invention.

[0031] Figure 5 is an enlarged view of air flow between a pair of tabbed fins of the present invention. As shown, the fin bodies 520, 521 have tabs 510 extending at a height, H_{TAB}, from the fin surfaces 528, 529. The fin bodies 520, 521 are separated by a fin separation distance, $D_{F.S.}$, and the tab height, H_{TAB}, is selected to be about one half of the fin separation distance, $D_{F.S.}$. While the tab height may be varied, the illustrated embodiment is useful because in typical finned tube heat exchangers a boundary layer is formed on each fin surface 528, 529 as the incoming air, A_{IN}, flows through the fins 520, 521 from the fin body leading edge 530, 531 toward a fin body trailing edge 532, 533. As can be seen, the boundary layers extend outward from the fin surfaces 528, 529 creating an insulting layer that ends at about a midpoint between the fins 520, 521. Hence, it is desirable to have the tabs 510 extend at a height, H_{TAB}, that allows the fin material, i.e., the material in the tabs 510, to extend into the outer portions of the main boundary layers and into the coolest air flowing through the fins 520, 521. Again, the tabs 510 are illustrated as being substantially planar with a square shape with rounded or smoothed shoulders 514 to reduce snagging or filtering of debris in the air, A_{IN}.

[0032] Figure 6 is a top view (or side view) of a fin 600 fabricated according to the invention. As shown, the cool air, A_{IN}, flows across first a leading edge 611 of the fin 600 then across a first surface 610 of the fin body. The air then contacts a fin collar (and

included tube not shown) 636 causing the creation of a wake or low pressure area 640 behind the collar 636 (and tube) and then, the air continues along the fin surface 610 until it passes over the trailing edge 612 where it is expelled as hotter air, A_{OUT}, of the heat exchanger in which the fin 600 is installed. The fin 600 includes numerous tabs that are formed by punching out section of the fin body (but leaving the material attached on one edge) and bending or hinging the material upward toward the surface 610 or downward toward the opposite surface of the fin 600. This can be seen with a first tab 614 that is bent downward relative to the surface 610 and the removed material forms a tab opening or hole 616 adjacent the tab 614. A second tab 620 extends upward relative to the surface 610 at a substantially right angle with the removed material (i.e., the material retained in tab 620) creating a tab hole or opening 622 adjacent the tab 620. As shown, the tab holes 616, 622 (and corresponding tabs 614, 620) are substantially square in shape but other embodiments of fins of the invention may utilize other shapes.

[0033] As shown, the tabs are arranged generally in rows that extend substantially parallel to the leading and trailing edges 611, 612 of the fin 600. Note, that this particular configuration is not required but is useful for ease of tab pattern selection (such as relative to amount of surface area to be utilized), for ease of manufacturing, and for assuring that tabs are positioned to achieve a desired sequentially offset arrangement. The offset feature of the invention can be seen by looking at the tabs in Rows 1-4 and particularly the four tabs of Rows 1-4 shown with the dashed line 630 that can be said to be corresponding or adjacent tabs in adjacent ones of the Rows 1-4. Row 1 can be thought of as the first row or most upstream row of tabs with Row 2 being the second row and immediately downstream row relative to Row 1 (or adjacent to Row 1). The tabs shown by line 630 in Rows 1 and 2 can be seen to be offset from each other. Likewise, the tab in element 630 in Row 3 is offset from the tab in element 630 in Row 2 (immediately upstream or in the adjacent row), and the tab in element 630 in Row 4 is offset from the tab in Row 3.

[0034] The amount of offset can vary to practice the invention, with the offset shown being one useful embodiment, e.g., the opening and tab in the downstream row is positioned substantially in the space between adjacent openings/tabs in the upstream row. Note, also, that the tabs in the element 630 are offset on a "diagonal" and this

pattern is continued in several additional rows of tabs. However, other offset patterns may be utilized as long as corresponding tabs in adjacent rows are offset from each other. Preferably, the offset pattern is selected so as to provide a spacing between similarly positioned tabs, such as by skipping a number of rows before placing a tab in a similar position within a row (e.g., as shown in Figure 6, a pattern of 8 rows is used with 7 rows provided as a "spacer" before repeating a row pattern).

[0035] Figure 6 also illustrates that the pattern of tabs may be relatively uniform or as shown, denser in areas of anticipated high flow of the cooling gas or air. Hence, as shown, there are fewer tabs placed behind the fin collar 636 (and other collars) where a wake is created by the collar 636 and, therefore, later installed tube (not shown). In this manner, a larger percentage of the tabs (and therefore, the area or material taken of the fin body 610) are placed in locations in between adjacent fins were heat transfer is most likely to occur effectively.

[0036] In some embodiments, a subset (such as a small percentage such as 10 percent or less) of the tabs are purposely not aligned with the main air flow through the fin (i.e., not perpendicular to a leading edge of the fin) but are instead skewed or angled relative to the main flow path or flow direction of the cooling gas so as to act as directional vanes. Typically, these directional vane tabs are positioned near (e.g., beside and/or slightly behind) the collars (and inserted tubes) of the fins to direct the air or gas flow into areas that otherwise would be starved for flow such as in the wake region behind the collar/tube. In other cases, the direction vane tabs may be further upstream to begin diversion of flow to the wake area prior to the tube collar and tube so that the flow redirection can be more gentle, i.e., less dramatic or turbulent. In one embodiment, at least some of the tabs near the collar 636 are angled to direct some air flow from the main flow path into the wake region 640. Preferably, the angle for the directional vane tabs is selected so as to avoid or minimize the creation of vortices behind these tabs so as to control increases in pressure drop, e.g., the angle may be less than 5 degrees and the like. Unlike a delta winglet pair, the tabs in this embodiment gently direct the flow into the wake regions without causing turbulence. The reduction in wake size reduces form drag and overall pressure drop while at the same time providing better heat transfer coverage in the wake region behind the tubes/collar.

[0037] The introduction of the fins, although parallel to the flow path, does alter the flow of the cooling gas relative to the fin, such as by increasing friction and by creating multiple thermal boundary layers within the gas flow channel or passage. In some embodiments, patterns of the tabs are selected with the express purpose of gently redirecting flow of the cooling gas. For example, the pattern of the tabs are selected purposely to fold or direct more of the cooling gas into the wake areas and areas of low pressure or flow between two fins. In one case, the tabs are offset in diagonal patterns to gently (e.g., with minimal turbulence) toward the wake regions behind collars and tubes.

[0038] In still other embodiments of the invention (not shown), fins are fabricated according to the invention so as to generate at least some vortices in the cooling air or gas. In one vortex generating application, the tabs illustrated and described in the invention are utilized in combination with delta winglet pairs, such as near the tube collars or other areas of low flow. In this manner, the beneficial effects of the tabs of the present invention and of winglet pairs are combined to enhance heat transfer. The amount of pressure drop can be controlled by limiting the number of winglet pairs utilized, and/or this embodiment may be employed when a higher pressure drop is acceptable. In another vortex generating application, tabs that are sharply angled (such as over 5 degrees up to 90 degrees) relative to the main or local flow paths of the cooling gas are included on a fin. Typically, in these embodiments of the invention, the majority of tabs would remain aligned parallel with the main or local flow paths with a minority or small number of unaligned tabs being added in strategic locations, such as locations at which winglet pairs are often employed or other locations at which it is desirable to create turbulence.

[0039] Figure 7 illustrates a section of the fin 600. As shown, the tab 620 is formed by bending material upward from the surface 610 to form a hole or opening 622 in the fin 600. Tab 614 adjacent to tab 620 in the tab row is formed by bending material downward from surface 610 to form the hole or opening 616. The tabs 614, 620 are bent away from the fin (e.g., from surface 610 for fin 620) at a selected angle, i.e., a bend or punch angle, θ, that is typically selected to be about 90 degrees for ease of manufacturing but similar heat transfer results may be achieved at smaller bend angles such as between 30 and 90 degrees.

[0040] Figure 8 illustrates another embodiment of a fin 800 formed according to the presenting invention. The fin 800 may be useful in heat exchangers in which fins are utilized without tubes. The fin 800 also illustrates a more regular pattern of tabs and openings than in Figure 6 with the offset clearly being on a "diagonal," i.e., with tabs in adjacent rows being offset a selected distance from the immediately upstream row.

[0041] Figure 9 is a graph 900 of the exemplary flow paths of a gas at about 1 to 3 meters/second across the surface of a fin such as the fin 600 in Figure 6. As can be seen, most of the flow is along a path generally between the tubes or perpendicular to the leading edge of the fin. Note, that over much of the fin surface the flow is predominantly in one direction with the path lines changing only slightly with distance from fin surface. Hence, except very near the tubes or in the wake regions, aligning the tabs on a fin along the main flow direction is sufficient to avoid or control introduction of drag. Such knowledge of the flow led to the design of the tabbed fins shown in Figures 2-8 in which the tabs are generally planar and aligned with the flow, i.e., positioned with their larger planar surfaces parallel to the main flow path shown in Figure 9.

[0042] While machining costs and pressure drops may be increased, some embodiments of the invention can be fabricated with the tabs aligned more particularly with the flow path of gas corresponding to the location of the tab, e.g., alignment along the local flow path lines. In other words, the tabs may be arranged with many differing alignments to suit the flow in that particular region of the fin. It is expected, though, that the placement of the tabs in the fin would change the flow relative to the fin and it may take numerous iterations to "match" such a tab alignment to the flow. Additionally, flow patterns vary with other parameters such as gas or air velocity and the like.

[0043] An exemplary tabbed-fin was fabricated according to the invention (similar to that shown in Figure 6) to allow the effectiveness of the above described invention. To fabricate small test cores for transient testing, a punching tool was used in conjunction with a template from a CAD program. The inventor used aluminum fin material as is used for finned-tube condensers with ½-in. tubes to fabricate fins for testing. An example of the template 230 and fins 210 are shown in Figure 2.

[0044] Measurements at air flow of 3 m/s showed that the tabbed fins provided 68% more air-side heat transfer and had a 33% higher pressure drop than similar untabbed fins. For comparison purposes, small cores made up of advanced fin materials were also tested, e.g., wavy fins and louvered fins. These cores were of a different fin density, but it was believed useful to compare the performance of the tabbed fins to the plain fins for these other arrangements designed for enhanced heat transfer. Table 1 shows the test results for these cores and compares the results to the results obtained for the tabbed fins of the invention. Note that the wavy fins and louvered fins were in a test core containing only one row of tubes. Also, the tabbed fin design had fins spaced at only 5 fins per inch (0.20 inch spacing) because that was the stock available. The tab-forming tool used produced tabs that are 0.050 inch on a side, so each tab extended only one-quarter way across the gap whereas it is believed that tabs that extend halfway across the gap perform better.

1. **Enhancement Type**	**Percent Change in Heat Transfer**	**Percent Change in Pressure Drop**
Wavy fins (one tube row)	-5	45
Louvered fins (one tube row)	56	136
Tabbed fins (3 tube rows)	68	33

Table 1. Percent changes in heat transfer and pressure drop for enhanced fins on ½-inch tubes compared to a reference of the same geometry but with plain fins (3 m/s approach velocity).

[0045] The above disclosure sets forth a number of embodiments of the present invention. Other arrangements or embodiments, not precisely set forth, could be practiced under the teachings of the present invention and as set forth in the following claims. Particularly, the use of tabs aligned and configured as discussed in the above description is readily useful with fin arrangements other than parallel plate arrangements. For example, air-cooled condensers are often configured with tubes upon which fin

material (such as aluminum foil) is helically wound. Such condensers may readily incorporate tabbed fins to enhance heat transfer, such as by punching the fin material prior to winding onto the tube.

I CLAIM:

1. A method for fabricating a heat transfer fin for a heat exchanger, comprising:

providing a plain fin for use in a heat exchanger with a fin body having first and second sides;

selecting a tab pattern for the plain fin, wherein the tab pattern defines a quantity of and location of heat transfer tabs; and

forming the heat transfer tabs defined in the tab pattern by creating openings in the plain fin by removing material from the fin body while retaining a connecting edge between the fin body and the removed material;

wherein the forming is performed to bend the removed material to a bend angle relative to the first or second side and wherein the formed tabs are substantially planar with a majority of the tabs aligned to be parallel to a predetermined direction.

2. The method of claim 1, wherein the predetermined direction is an anticipated main flow path for a cooling gas across the fin body.

3. The method of claim 2, wherein the fin body includes a leading edge and the majority of the tabs are aligned perpendicular to the leading edge.

4. The method of claim 2, wherein a minority of the tabs are direction vanes at an angle of less than 5 degrees from the main flow path to direct flow of a gas flowing over the minority of the tabs into anticipated wake regions.

5. The method of claim 1, wherein the tab pattern is selected such that during the tab forming a first portion of the tabs are bent to extend from the first side and a second portion of the tabs are bent to extend from the second side at the bend angle.

6. The method of claim 5, wherein the bend angle is between about 30 and 90 degrees.

7. The method of claim 1 wherein the tabs extend a tab height measured from fin body, the tab height being less than about a half a fin separation distance.

8. The method of claim 7, wherein the tab pattern is selected such that a the created openings have a surface area that is less than about 50 percent of the area of the first side of the fin body.

9. The method of claim 8, wherein the surface area of the created openings is between about 10 and 25 percent of the area of the first side.

10. A fin for use with tubes in a finned-tube, air-cooled heat exchanger, comprising:

a metallic fin body with first and second heat transfer surfaces and a leading edge;

tube collars formed in the fin body for receiving and contacting the tubes of the heat exchanger;

a plurality of tabs extending at a bend angle from the first and second heat transfer surfaces, wherein the tabs are substantially planar with a majority of the tabs aligned to be parallel with each other and substantially perpendicular with the leading edge of the fin body; and

air passages extending through the fin body adjacent to and corresponding in shape to the tabs.

11. The fin of claim 10, wherein the bend angle is between about 70 and 110 degrees as measured from the first or the second heat transfer surface.

12. The fin of claim 10, wherein about 50 percent of the tabs extend from the first heat transfer surface.

13. The fin of claim 10, wherein the tabs have a height as measured from the first or second heat transfer surface that is less than about half of a predetermined fin separation distance for the heat exchanger.

14. The fin of claim 10, wherein the tabs are generally square or rectangular in shape and include at least a partially curved shoulder at a leading edge.

15. The fin of claim 10, wherein the tabs are positioned on the fin body such that the tabs are less densely distributed in a wake region near the tube collars and distal to the leading edge of the fin body.

16. The fin of claim 10, wherein the tabs are arranged in rows relative to the leading edge in which a first portion of the tabs extend from the first heat transfer surface and a second portion of the tabs extend from the second heat transfer surface.

17. The fin of claim 16, wherein each of the tabs in each of the rows is offset an offset distance relative to corresponding ones of the tabs in adjacent ones of the rows.

18. The fin of claim 16, wherein adjacent ones of the rows are offset relative to each other such that the tabs in the adjacent rows are not coplanar.

19. An air-cooled heat exchanger, comprising:

a plurality of conduits for passing a hot fluid through the heat exchanger; and

a plurality of fins attached to the conduits, the fins being spaced apart a fin separation distance and defining an air flow passage between adjacent pairs of the fins;

wherein the fins comprise:

a metallic fin body with first and second sides and a leading edge; and

a plurality of tabs extending at a bend angle from the first and second sides, wherein the tabs are substantially planar with a majority of the tabs aligned to be parallel with each other and substantially perpendicular with the leading edge of the fin body.

20. The heat exchanger of claim 19, wherein the tabs are arranged in rows relative to the leading edge in which a first portion of the tabs extend from the first heat transfer surface and a second portion of the tabs extend from the second heat transfer surface and wherein adjacent ones of the rows are offset relative to each other such that the tabs in the adjacent rows are not coplanar.

21. The heat exchanger of claim 19, wherein adjacent pairs of the fins are connected and the fins comprise metallic foil, and wherein the fins are attached to the conduit by winding in a helical pattern about the outer surface of the conduit.

22. The method of claim 2, wherein a minority of the tabs are vortex generators and are aligned at an angle greater than 5 degrees relative to the main flow path of the cooling gas.

23. The method of claim 22, wherein the minority of the tabs are positioned proximal to a wake region for the plain fin.

24. The method of claim 2, wherein the tab pattern is selected such that at least a portion of the tabs extending from the first or the second side are arranged to direct flow to areas of low flow for the plain fin.

25. The fin of claim 10, further including a plurality of delta winglet pairs on the first and second heat transfer surfaces of the fin body.

26. The fin of claim 25, wherein the delta winglet pairs are positioned proximal to the tube collars.

27. The method of claim 1, wherein the tab pattern is selected such that the heat transfer tabs only extend from the first or the second side.

28. The method of claim 27, wherein the tabs extend a tab height measured from the side of the fin body from which the tabs extend, the tab height being less than about a fin separation distance.

29. The fin of claim 10, wherein a minority of the tabs are aligned at an angle relative to the majority of the tabs, the minority of tabs being positioned proximal to the tube collars and the angle being selected to direct a gas flowing over the fin body around the tube collar.

26. The fin of claim 25, wherein the delta winglet pairs are positioned proximal to the tube collars.

27. The method of claim 1, wherein the tab pattern is selected such that the heat transfer tabs only extend from the first or the second side.

28. The method of claim 27, wherein the tabs extend a tab height measured from the side of the fin body from which the tabs extend, the tab height being less than about a fin separation distance.

29. The fin of claim 10, wherein a minority of the tabs are aligned at an angle relative to the majority of the tabs, the minority of tabs being positioned proximal to the tube collars and the angle being selected to direct a gas flowing over the fin body around the tube collar.

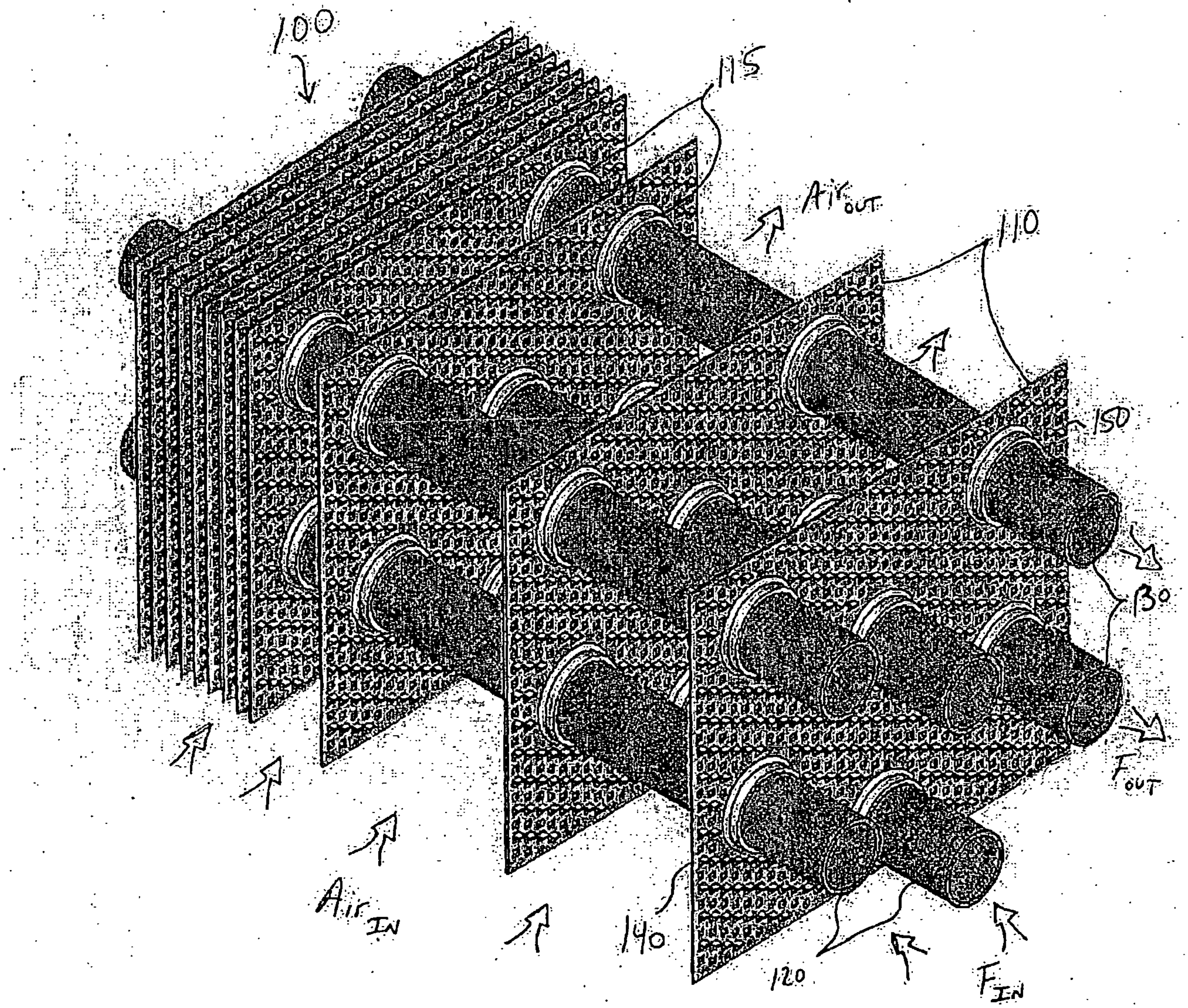

FIG. 1

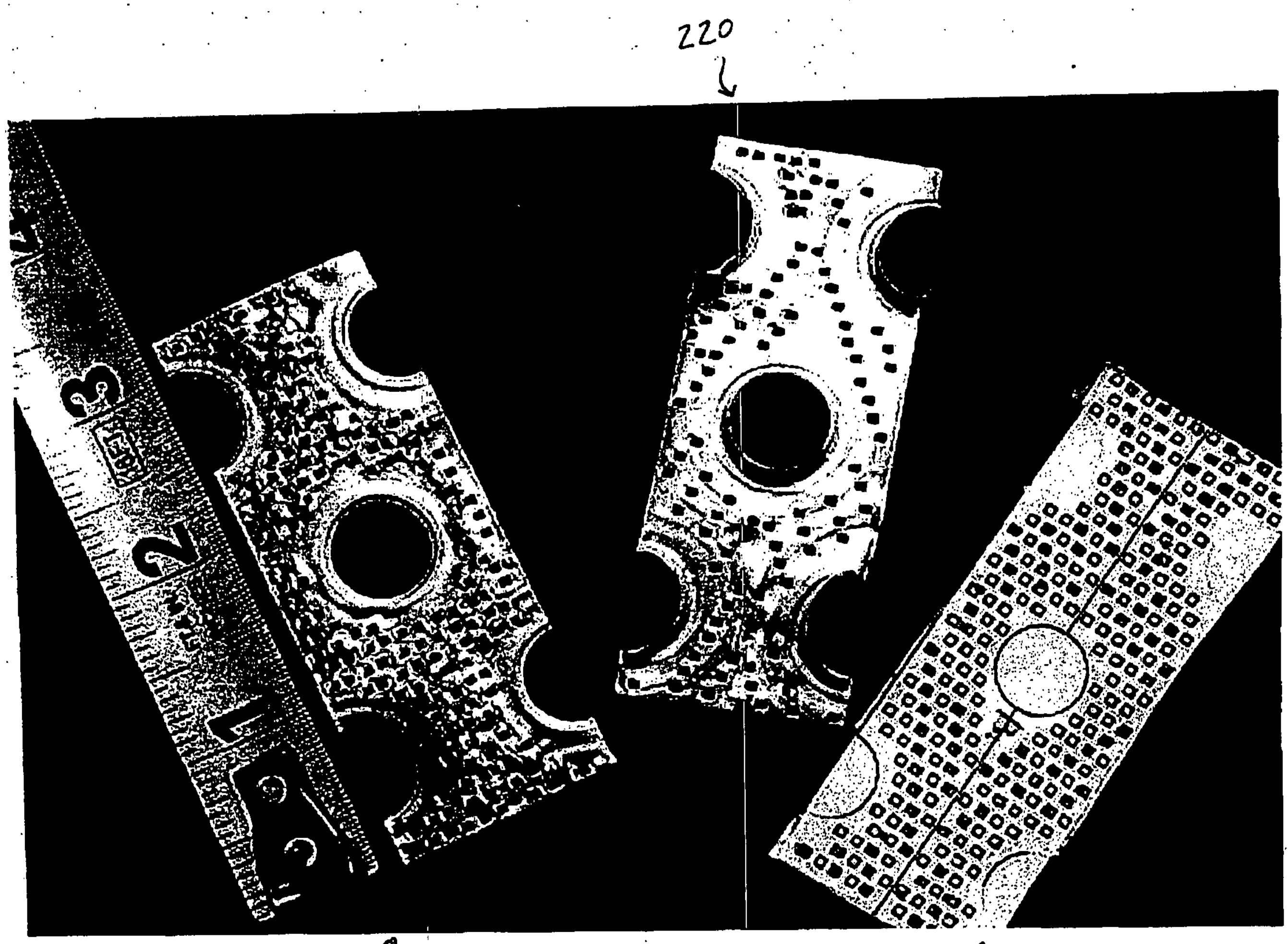

FIG. 2

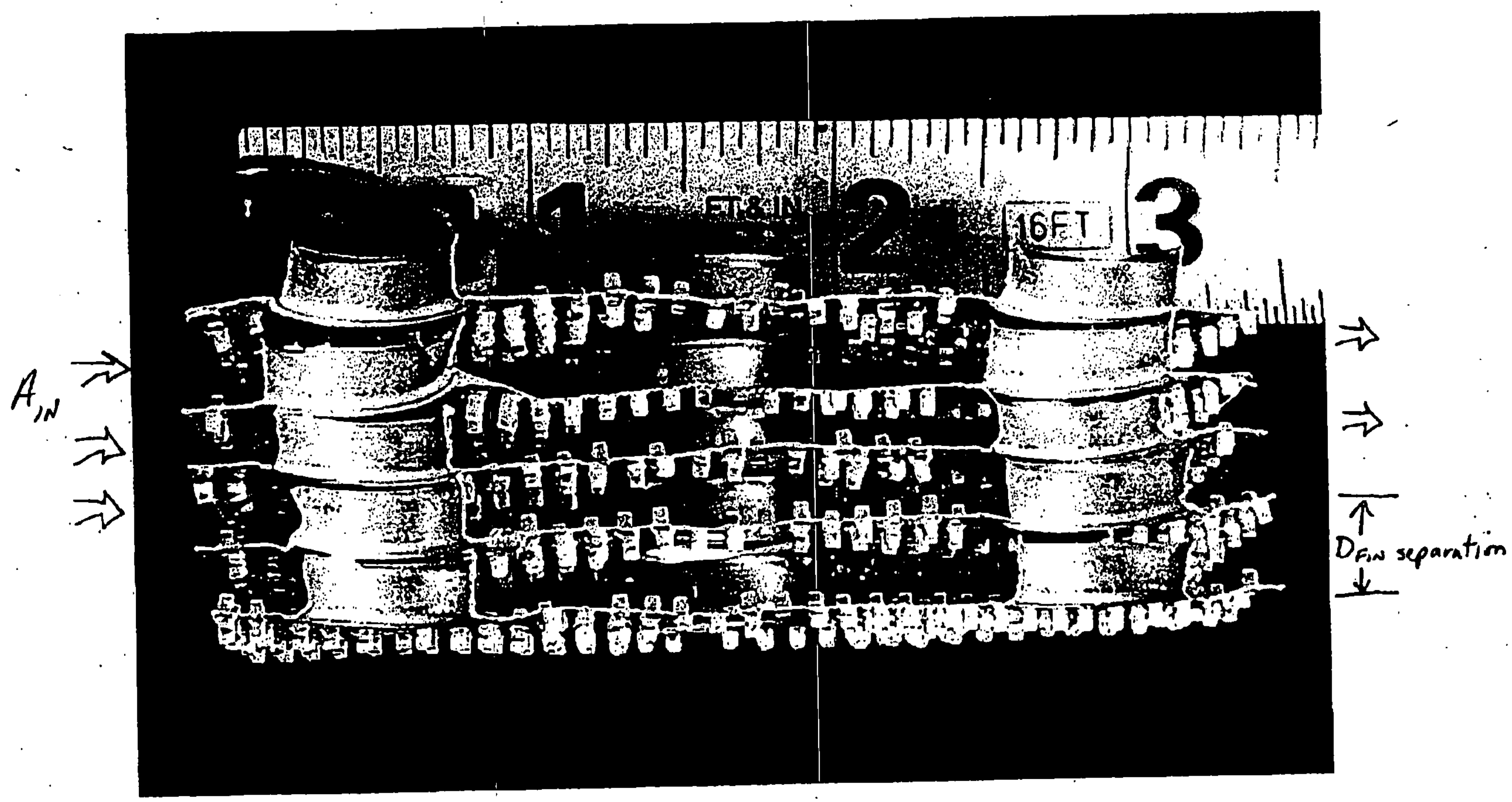

FIG. 3

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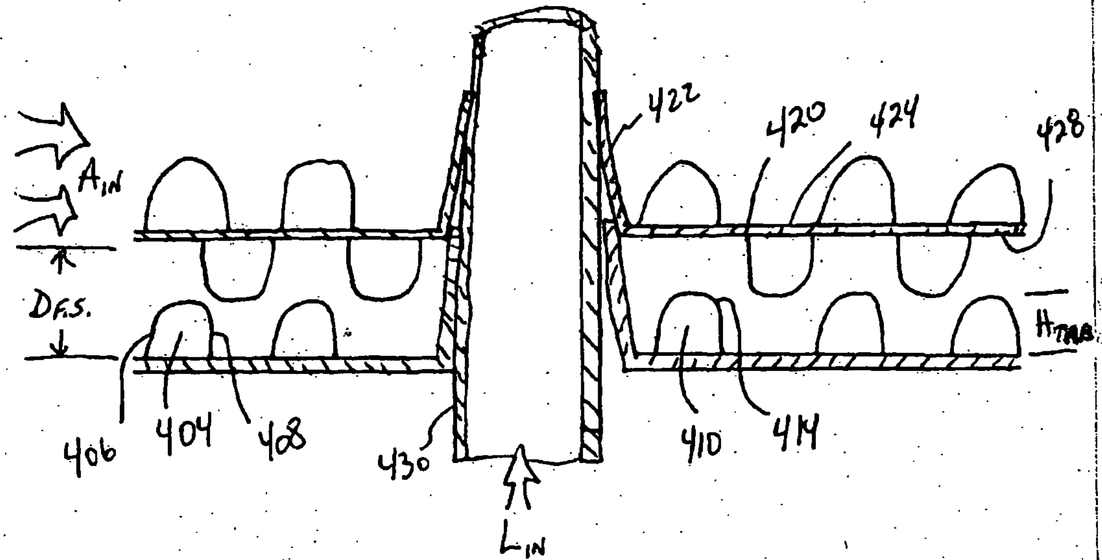

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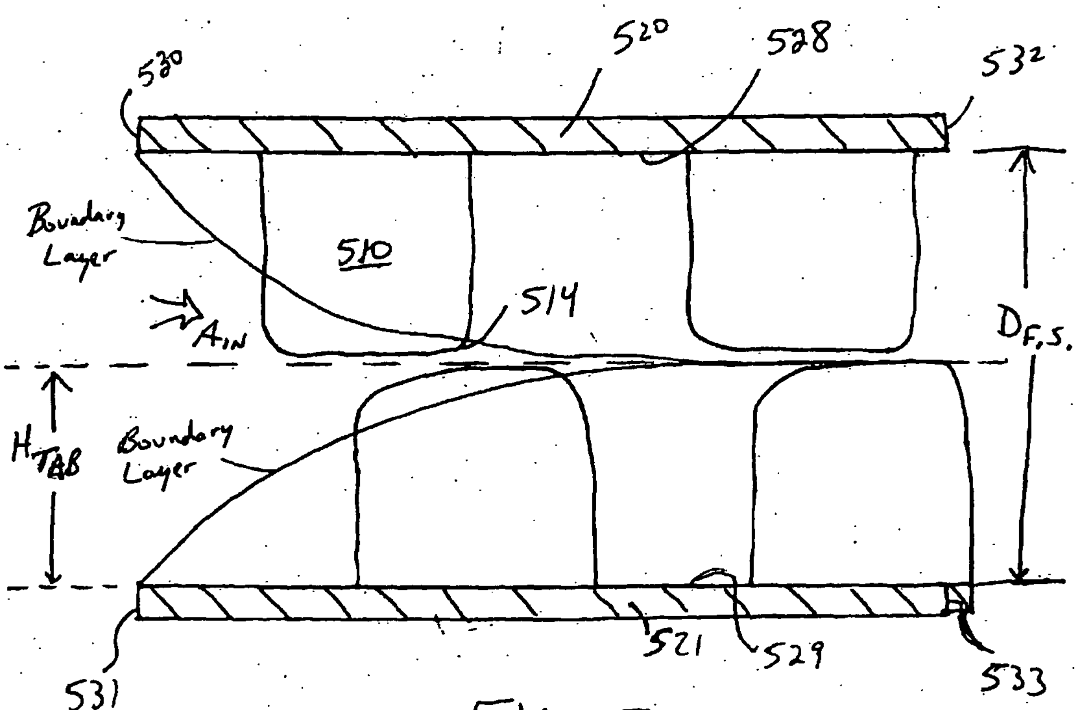
414

FIG. 4



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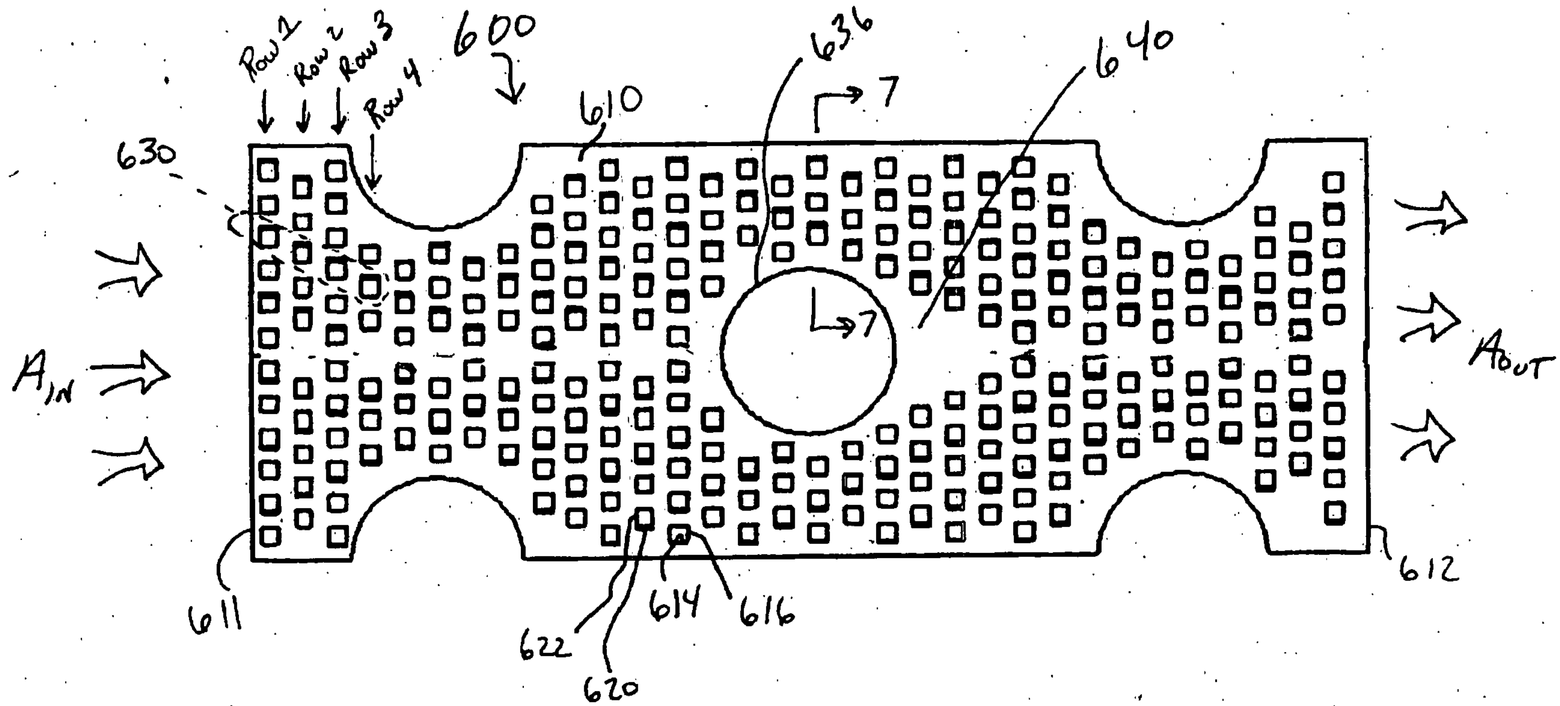
533

FIG. 5



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614
616
612

FIG. 6

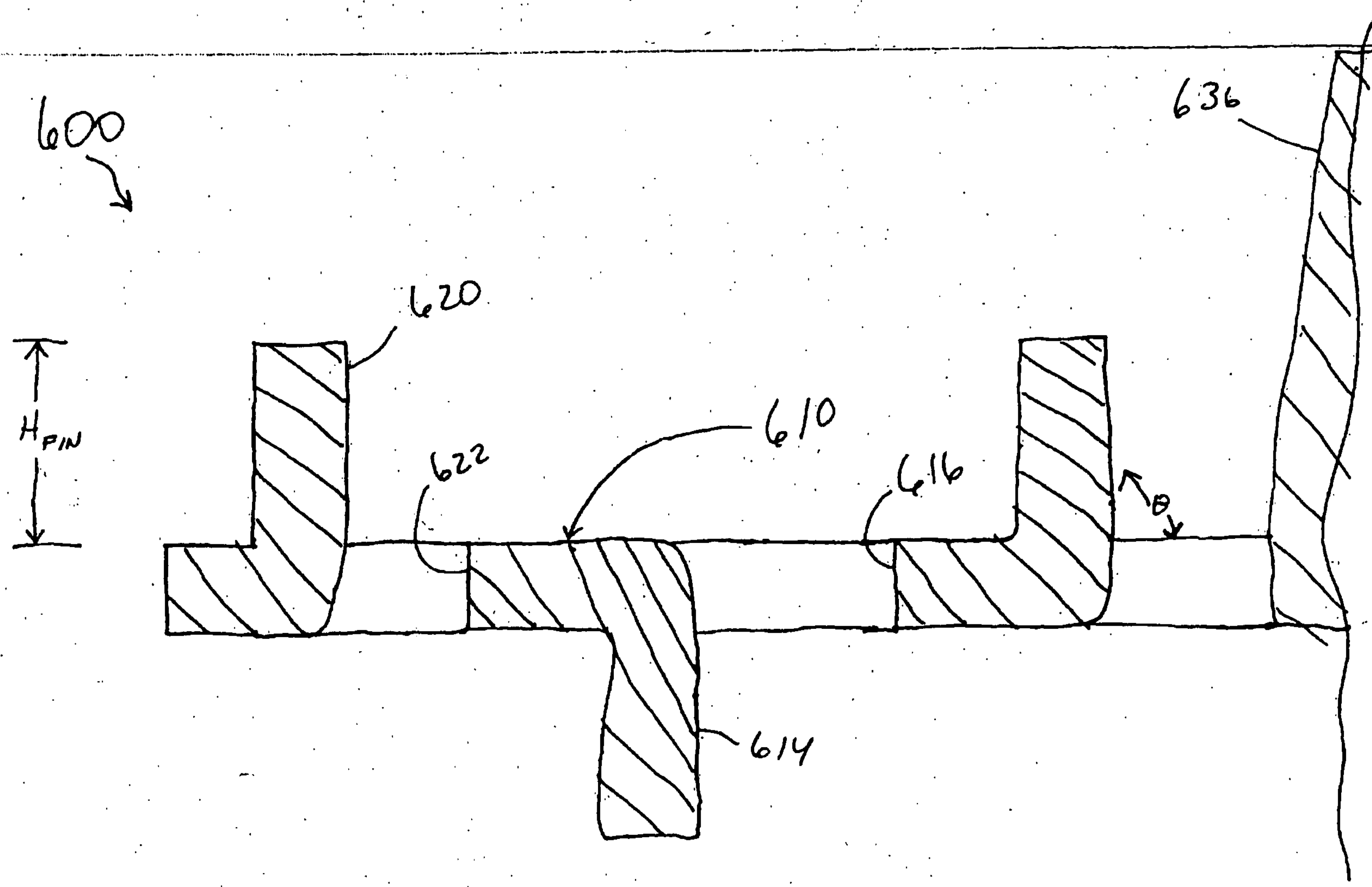

FIG. 7

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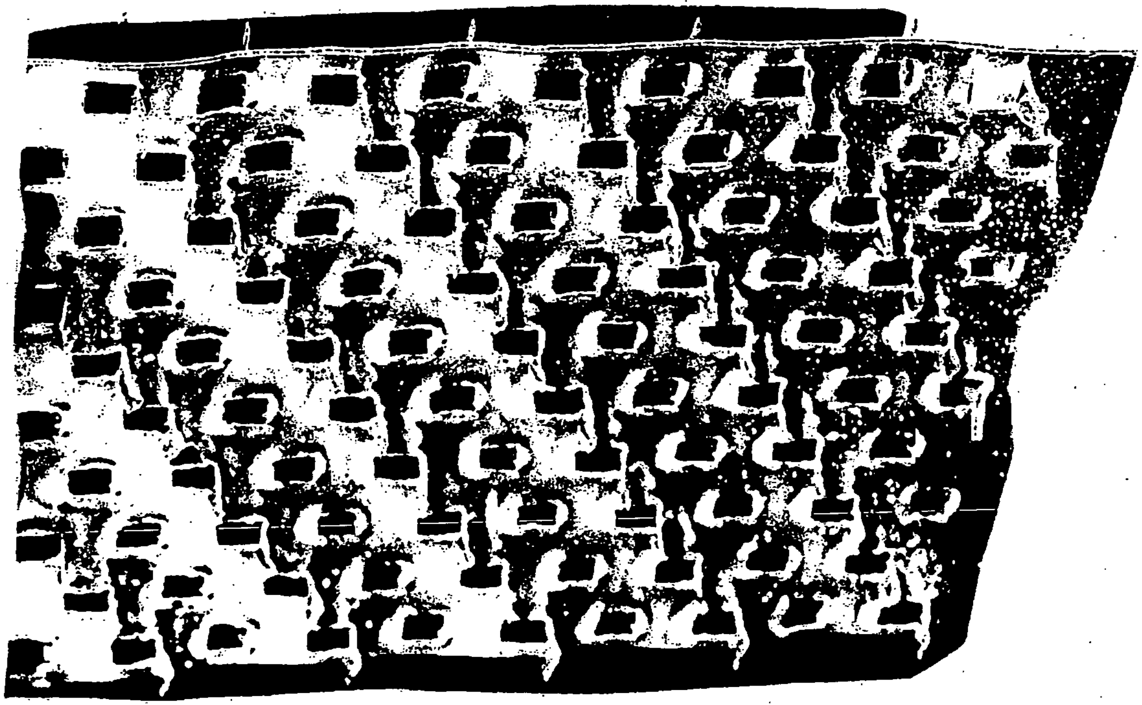

FIG. 8

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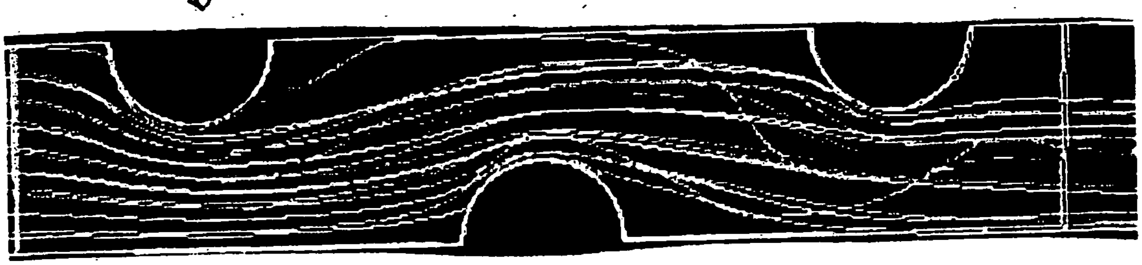

FIG. 9

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